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Comprehensive Analysis of Water Supply Shortage and Solutions in California

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1. Abstract

Water is a very precious resource, it supports the lives of billions of people. However, due to a series of problems, water shortage becomes more prominent. [1]. This shortage causes not only economic slowdown, but also mortal illnesses and regional conflicts. Water shortage is occurring more frequently around the world in both developing and developed countries and arouses interest in its causes.

This report will study water shortage in California. According to the California Department of Water Resources, the water demand in California mainly comprises of three domains in which 50% is for environmental use, 40% is for agricultural use, and 10% is for urban use [2]. For environmental use, the water is mainly for preservation of the ecology in some protected regions under the federal and states laws, and for maintaining the water quality for agricultural and urban uses [2]. Although environmental use is related to the hydrology in California, it indirectly affects human activities and significantly consume the water as compared to other uses – mainly agriculture.

In the last few decades, due to the increasing yield of crops, and the switch to perennial crops [2], water usage dropped slightly for the industry. However, agricultural industry still relies on stable water supply heavily in order to produce good-quality, profitable crops. Being one of the major industries in California, which contributes to approximately 2% of the GDP of the state, together with other derived production profits [3], the water supply plays an important role in sustaining the economy of the industry and California.

By comparing climate and agricultural data to the drought level in California as defined by the United States Drought Monitor (USDM), this report will provide an analysis of the causes of water shortage in California and compare and suggest solutions to mitigate the issue.

2. Introduction

2.1. Drought Situation in California

California suffered an extraordinarily severe period of drought from Jan. 2014 to Dec. 2016. In 2015, which was the peak of the drought, all counties in the state were experiencing drought, and over 58% suffered from exceptional drought [4]. The drought in California can impact the lives of its whole population of nearly 40 million people. The drought has caused rapid changes in water policies and stress among citizens in California. The recent drought has subsided beginning Jan. 2017, but California's government and its citizens are still acting to establish better water supply management.

2.2. Drought Measurement in the United States

In the United States, the United States Drought Monitor (USDM) classifies drought categories by measures such as soil moisture, streamflow, precipitation, and reservoir and groundwater levels, using different categories from D0 to D4 with D4 being the most severe level of drought. [4] The Drought Severity and Coverage Index on the other hand is defined as the following categorical weighted sum:

$$1(D0) + 2(D1) + 3(D2) + 4(D3) + 5(D4) = DSCI$$

2.3. Current water consumption

According to United States Geological Survey [5], which compared water usage data in California in 2005 and 2010, surface water extraction decreased from 35 billion gallons per day to 25 billion gallons per day. However, groundwater withdrawal has reverse trend comparing with the one of surface water. It increased from 11 billion gallons per day in 2005 to 13 billion gallons per day, which is 33% of total water consumption in California, in 2010. The usage of groundwater varies with season. From California Department of Water Resources [6], groundwater provides maximum 46% of the total water consumption in California. Undoubtedly, groundwater acts as unexpendable role in California. Groundwater supply in California has water stress situation. From Spring 2017 Groundwater Level Data Summary [7], 44.4% of the inspection well in the state showed more than 5 feet decrease in groundwater level since 2011 Spring. In Tulare Lake and South Coast had 40.9% and 64.6% inspection well showed more than 25 feet decrease in groundwater level respectively. The great percentage of reliance on groundwater in drought season and decreasing availability of groundwater will cause more severe drought situation in California.

2.4. Causes of Water Stress in California

California has a highly variable climate among US states, often experiencing high precipitation years after severe drought years [8]. Overall, as shown in Figure 3.4, the climate in California is hot and dry, which leads to a heavy burden on reservoirs. However, very few water projects have been built since 1979 [9], despite a doubled population in California. The deterioration of the water system also contributes to the water stress [10][11]. Accumulation of contaminants in surface and groundwater, e.g. fertilizers, pesticides, and other chemicals lift the cost of farming, drinking water and wastewater treatment. However, the focus of this report will be on climate and agriculture.

3. Literature Review

3.1. Current government policies

Several measures by the government are now being established to handle water shortages in the future. One of the most dramatic policies involve the 20% cut on water supplies such as drinking water and water consumption by households [12]. Meanwhile, in response to the prolonged drought, the state created a \$7.5 billion water bond with the following amounts in millions for each category as shown in Table 3.1.[13] For example, \$2,700 million (36% of bond), which is the largest percentage of the bond, will go into creating new dams/reservoirs, and currently, there are 12 projects being considered for the funding. [14] On the other hand, \$1,495 million (~55% of bond) will go to protecting streams, and so on.

3.1.1. Benefits

The bond by the government, including the size of the bond, can lead to a large increase in water management infrastructure. The large amount going into creating new dams and reservoirs can also significantly reduce the drought levels in California by increasing the reserve capacities. Meanwhile, the \$900 million going into groundwater sustainability will not only allow more reliable reserves during drought periods, but it can also reduce land subsidence.

3.1.2. Limitations

The water bond also has its limitations, with the main limitation being that the actual project proposals have not yet been fully developed. Thus, it will be long before the bond can take full effect on California's water management systems. This is because a thorough analysis of all proposed projects will be needed to select the most valuable projects, yet even the most valuable or most innovative projects can take time and more effort to build.

3.2. Conventional desalination

Desalination is a series of chemical and physical reactions that extracts water from brine to support the demand of fresh water. Common desalination methods include multi-stage flash distillation (MSF), Multiple-effect distillation (MED) and vapour-compression evaporation (VC). In particular, countries in the Middle East and the Arab are sophisticated in multi-stage flash distillation (MSF) which contributes to 50% of desalination capacity worldwide [15]. MSF is a continuous reaction between evaporation and condensation of seawater. By feeding seawater into series of 15-25 specially designed chambers and heating them with some chemicals, the seawater would carry lower boiling points in the low pressure chambers. The water is more favourable to separate from the salts by evaporating to steam. The steam is then condensed to fresh water for usage. As shown in figure 3.2, the feeding seawater are injected into the chamber as a cooling agent for the condensation of the heated steam. Under the special condition of low pressure and high temperature in the chamber, the seawater starts to evaporate to steam below its boiling point in room condition. This reaction is known as "flash".

3.2.1. Benefits

A desalination plant is relatively simple to construct and operate because this technology relies mainly on physical reaction (i.e. state change of water) which is a well-developed technology [15]. Moreover, desalination is effective to produce high quality of fresh water with very small amount of dissolved solids (i.e. up to 10 ppm) [15]. This high purity makes the technology a lower cost in post-treatment.

3.2.2. Limitations

MSF is very demanding in energy and expensive. Since water is with relatively high specific heat energy and latent heat, the continuous change of states of seawater requires a lot of electricity [16]. Furthermore, apart from the operational fuel cost in sustaining the reactions, the large amount of seawater required increases the transportation cost significantly, especially if the treatment plant is far away from coastal area. Also, this technology is season-dependent [17]. Considering the crucial high temperature used to maintain the evaporation of seawater, the plant have to be capable to work in winter as well, which in turn increases the initial investment of the plant.

3.3. Fog collection

Fog harvesting technology use simple single or double layers mesh net of different fiber materials supported by posts at either end. The collectors could consist of complex structure, and the mesh could vary in size depends on the districts [18]. Water molecules in fog condense on the surface of fiber materials and flow down along the grid, then drip into a gutter at the bottom of the mesh net. Water finally channelled through the pipes to a water tank.

3.3.1. Benefits

The water collected is generally clean and suitable for irrigation uses without extra water treatments. The collection system is relatively easy to construct on site because the connection between the components is simple, which does not need professional knowledge. Moreover, the investment costs and maintenance cost are comparatively low because materials are common and could be easily produced in factory. Besides, the technology is environmentally friendly. It does not require extra energy for operating and cause minor effects to the surrounding environment.

3.3.2. Limitations

Fog harvesting technology always limited by the weather and geographic condition of the districts. The function of this technology may not well operate under some conditions that the frequency of occurrence of fog is low. In coastal regions, condensated water may contain higher concentration of chlorine, nitrate and other elements [18]. Besides, extra costs is needed if the harvesting region does not close to the demand regions due to water transportation and maintenance fee. Moreover, this technology could not provide steady water supply because of the variety of weather .

3.4. Purchase Water from Other States

According to Figure 3.4, the West Coast of the US has a dry climate where the East Coast has a humid climate. California is located at the West Coast, which is on average the driest region in the US. California is surrounded by Oregon, Nevada and Arizona. These states should have less water deficit in theory, and the California State government can buy the water from these states to solve the drought in California.

3.4.1. Benefits

The water shortage problem can be solved with the extra water source. Any water deficit can be filled with the purchased water provided that there is a sufficient amount. Being the largest contributor of the national GDP [3], California should have adequate purchasing power to buy water from other states. The cost of operation per liter of water should be less costly than other methods with current technology.

3.4.2. Limitations

In order to transport water from neighboring states to California, pipes have to be built over a long distance. On average, the pipes have to be at least 200km long in order to transport the water to the center of California. The construction would be so large scale that it involves huge amount of human resources, capital and time. The initial investment would be so enormous it may take a long time to break-even. Also, such a construction requires inter-states politics, which involves processes such as price bargaining and legislative procedures in respective state governments. The processes involve complicated politics which is time-consuming.

3.5. Solar Desalination from WaterFX

Solar desalination from WaterFX is a startup working on sustainable fresh water supply in California which utilizes solar-thermal energy to support the operation of Multiple-effect distillation (MED) as shown in Figure 3.5.1 [15]. Similar to conventional desalination, solar desalination from WaterFX extracts impurities such as salts and dissolved solids in water from seawater in series of vessels called “effects” as

illustrated in Figure 3.5.2 so to support the demand of fresh water for both households and agriculture. However, the whole reaction process is driven by the solar energy instead of electricity from burning fuel. In addition to seawater, the solar desalination from WaterFX also performs desalination on drainage water in California. The solution currently generates over 200 acre-feet/year of freshwater per acre of solar collection area [19], which is translated to 1.6 billion gallons per year, and annual water consumption of 12,000 households.

This solution is different from conventional solar distillation from solar still illustrated in Figure 3.5.3 where fresh water is extracted by high temperature passive distillation [20]. Instead, the energy collected from the solar panels is used to support the heating of feeding water in the specially-designed chambers for the “flash” reaction.

3.5.1. Benefits

Solar desalination is sustainable to handle the shortage of freshwater in California because the whole mechanism is supported by renewable solar energy which will cause no burden to current fossil fuel consumption. Also, the raw material used in the reaction process are seawater and drainage water which are both abundant so the stability of supply is guaranteed.

This solution fits the landscape of California. Since more than 43% of the land in California is desert area [21] which is not suitable for urban development. Using these lands for solar panels can utilise the land in the rural area.

The climate of California is suitable for developing solar energy. Considering more than 284 sunny days per year in California (more than 75% of days in a year) [22], the solar panels can efficiently absorb the solar energy.

The Multiple-effect distillation (MED) adopted by WaterFX is flexible [23] due to its relatively small size. Unlike the plants in conventional desalination which require large space, this MED takes up only 6500 square feet [19]. Its small size makes it movable and convenient to install in different regions.

3.5.2. Limitations

Further development on the amount of freshwater generated is needed for the project. Since the project aims to support the long-term water consumption in California including both agricultural use and household use, the current output rate which can only support the water use of 12,000 household is not enough. Therefore, development in higher water generation rate is required.

Capital shortage is another hinder to the development. Since WaterFX is a startup company, although it is funded by several parties, the capital is far from enough to purchase large amounts of solar panels if the project aims to cover the whole state. Therefore, the insufficient initial investment limits the development of the technology.

4. Data

The following data was used for Section 5. Methodology & Analyses:

Drought Coverage and Severity Index (DSCI) [24] (USDM Drought Classes & DSCI vs Time)

Also available at: <https://drive.google.com/open?id=1hpIaq0DyK4KLULB1-mkYYmeh-5loEhY1>

Temperature and Precipitation in California [25] (Temperature & Precipitation vs Time)

Also available at: https://drive.google.com/open?id=1fPX_aaGgaQV0U2uhAxkZkYF_FigdZgeK

Relative Humidity in California Los Angeles International Airport [26] (Relative Humidity vs Time)

Also available at: https://drive.google.com/open?id=13A_8G37ziNzdKRBLAcXsPLK8lWYoaxT2

California Agricultural Net Farm Income [27] (Agricultural Income vs Time)

Also available at: <https://drive.google.com/open?id=10zLoiPhfcTMl9oBAUATLEy-k3FhxxMxC>

US GDP Deflator [28] (US GDP Deflator vs Time)

Also available at: <https://drive.google.com/open?id=1fKNlpmU3gONnKwK58466gLnDFSINyj23>
(refer to the highlighted column)

5. Methodology & Analyses

5.1. Drought History in California

5.1.1. Methodology

Simple plotting in Excel used for Figure 5.1.1 & Figure 5.1.2, Autocorrelation with maximum lag = 935 (due to having only up to 936 observations [24]) in R used for Figure 5.1.3.

5.1.2. Results

From Figure 5.1.1 & 5.1.2, there is an observable cyclic pattern of drought with a seasonality of approximately 6 years. This is confirmed by Figure 5.1.3, which is the plot of autocorrelation of the drought index D0 rating with the peaks in autocorrelation occurring at time-lag approximately 300 weeks, which is about 6 years. This suggests that California may face another drought with a peak in 2021 if no changes to water consumption/rainfall patterns are made.

5.2. Climate Effects (Temperature, Precipitation, and Relative Humidity) on Drought using Principal Component Analysis (PCA)

5.2.1. Methodology

To find out the climate effects on drought, Principal Component Analysis is conducted on the set of data of 4 variables - temperature, precipitation [25], relative humidity [26], and the Drought Severity and Coverage Index [24]. The data of 4 variables forms a matrix of 4 dimensions. By eigenvalue decomposition of the matrix, the original 4 variables can be transformed into 4 linearly uncorrelated variables called Principal Components (PC), which can retain the highest amount of information of the data while reducing the dimension of the data.

5.2.2. Results

In order to view the correlations of the variables, all data points are projected on the plane formed by the first two Principal Components (Figure 5.2). In this case, the first two Principal Components PC1 and PC2 can count for 42.8% and 30.1% of the variation in the data respectively, 72.9% in total, which is sufficient to show significant and valid results.

In Figure 5.2, the data points are grouped by season and the original 4 variables (in black arrows) are plotted on the graph. From the direction of the arrows, the correlations of the variables can be told. Among the 3 climate variables, the relative humidity shows the most correlation (in a negative way) with the Drought Index, but still not very significant since the arrow of relative humidity is the most parallel to and opposite to that of Drought Index. Unexpectedly, the temperature and precipitation are just very slightly correlated with the Drought Index (the arrows of temperature and precipitation are quite orthogonal to that of Drought Index).

The data points of different seasons are grouped by 4 ellipses and labelled with different colours. It reveals that the occurrence of serious droughts is independent of seasons, because the 4 ellipses all cover the region indicated by the positive Drought Index arrow (meaning serious drought).

5.3. Relative Humidity Effects on Drought in California

5.3.1. Methodology

Simple scatter plotting and regression line in Excel used for Figure 5.3. The data used from [26].

5.3.2. Results

Relative humidity (RH) represents the saturation of moisture content of the atmosphere. It always relates to the precipitation and moisture evaporation. RH in Los Angeles on average gradually decreases at a rate of $-0.438\%/year$ according to the data. The correlation coefficient of between relative humidity versus drought severity is -0.227 , which shows a slight negative relationship between RH and Drought Index. The decrease in relative humidity worsens the drought severity in Los Angeles.

5.4. Agriculture Effects on Drought in California

5.4.1. Methodology

In 2010, agricultural industry contributed approximately 40% of the water usage in California [3]. Being one of the biggest water consumers in California, it suggests that agricultural activities may have a strong correlation to the drought in California.

To analyse the relationship in a quantitative way, cross-analysis is done between two parameters.

The Drought Severity and Coverage Index (DSCI) is used as the parameter to illustrate the extent and level of drought because it provides a continuous, unified numerical value in chronological orders.

The agricultural activities can be quantified by the yearly net farm income, which is approximately proportional to the production level in macroeconomics perspective. However, the ratio between the volume and monetary value of crops fluctuate every year due to the external economic or financial situation. To be more precise on describing the volume of crops through the net income, the price level effect should be eliminated by dividing the net income by the GDP deflator of the same year, so that the nominal income can be converted to real income, which accurately shows the level of agricultural output of every year.

5.4.2. Results

DSCI is kept fixed and the real income shifts along the data start from time lag = 0 year. Figure 5.4.1 shows that the correlation coefficient is highest when the time lag = 2 years, with a value of 0.655. The value shows a relatively strong relationship between agriculture and drought, which can also be seen from Figure 5.4.2.

Moreover, as water supply is one of the major determinants of crops yield [12], farmers need to constantly adjust its level of output to maximise the profit by eliminating the marginal cost due to water shortage. The result from the time delay analysis suggests that this output equilibrium takes around 2 years to reach in aggregate level. Therefore, agricultural industry may not be able to swiftly react to the water level drop before the water reserve depletes, which worsen the drought situation even more.

6. Recommendations

6.1. Considerations & Justifications

Taking all causes and solutions reviewed into account, Solar Desalination is our proposed solution for the following criteria:

6.1.1. Sustainability

Since the plant is powered by renewable solar energy, it is more sustainable than conventional coal-fire electricity powered desalination. Meanwhile, the raw material of seawater is very abundant as compared to say fog collection, in which the yield is limited by the moisture content of the air. Furthermore, solar desalination can also process drainage water with high metal content to promote the concept of fresh water sustainability. Solar desalination is also more sustainable than purchasing water from other states because it will create a new source of water rather than using the already limited water sources and increasing transportation costs.

6.1.2. Economical Feasibility

Solar desalination will also have low operational costs because of the renewable nature of solar energy and abundance of seawater. There would mainly be maintenance cost and further investments would not be needed, especially with recent developments in solar technology, allowing the lifespan of the panels to be upwards to 30 years [29]. Furthermore, the pilot project by WaterFX demonstrates the feasibility of the technology in supplying 1.6 billion gallons per year to supply water to approximately 12,000 households [19]. While the current water bond proposed by the government will also significantly impact California's water management capabilities, the bond is focused more in increasing water capacity, and not on increasing the sources of water.

6.1.3. Market Penetration

The solar desalination plants are relatively smaller in size than conventional plants, with only 6500 sq. ft in area. Compared to other desalination methods, solar desalination is cheaper in both initial and running costs due to its small area footprint, components cost, and operational cost, which makes it affordable for municipal or town governments, and possibly even rural farmers can afford. The components used, such as the parabolic trough [30], are also readily available in the market, and this will allow the agriculture industry especially to utilize this technology and reduce strain on the water supply. Furthermore, the

whole working system is relatively simple, such that the general public can install the whole system without the need of extra costs from specialists.

With these criteria, solar desalination provides the most sustainable, economically feasible, and marketable solution among those reviewed to alleviate California's water supply shortage.

7. Conclusions

7.1. Summary

The severe drought in 2014-2016 in California reveals the water shortage problem in California. After analysing on drought history by autocorrelation, climate effect by principal component analysis and agriculture, using drought severity and coverage index and yearly net farm income for quantitative cross analysis, we can conclude agriculture is the major cause. Facing large consumption in agriculture, insufficient water project and deteriorating water system, the California state government chooses to solve this problem at the source. Through issuing water bond to raise fund for constructing dam and reservoirs. However, this method will be valid after long time. Other alternative solutions, such as conventional desalination, fog collection and purchasing water from other places. All these methods are not suitable because of high cost or weather and geographic restriction. Comparing with other alternative solutions, solar desalination is the most suitable method. Environmental sustainability, stable supply due to high percentage of sunny day in a year, flexible technology because of small size and availability of large landscape in California makes solar desalination become suitable and effective solution to water shortage in California. Although solar desalination in California just afford the supply of household consumption, there is still a huge potential to further develop for industrial consumption, such as agriculture.

7.2. Call to Action

The problem of water shortage is complex and deep-rooted, and therefore should be handled with the support of different stakeholders. The government should subsidize the project of solar desalination and relevant technologies to enable environmentally friendly and stable water supply. Due to the large water consumption in agriculture, the agricultural sector should endeavor to develop cultivation methods with lower water consumption, which is the most effective way to solve the problem at source. Also, the general public should be more aware on this issue. The general public can learn more about the solar desalination and even support the project via different means like crowdfunding. For example, the website of the startup WaterFX (<http://waterfx.co>) provides plenty of information about its solar desalination project.

8. Appendix

Water Storage	Protecting Streams	Groundwater Sustainability	Drought Preparedness	Water Recycling	Safe Drinking Water	Flood Management
\$2,700	\$1,495	\$900	\$810	\$725	\$520	\$395

Table 3.1 Distribution of \$7.5 billion water bond(in millions)

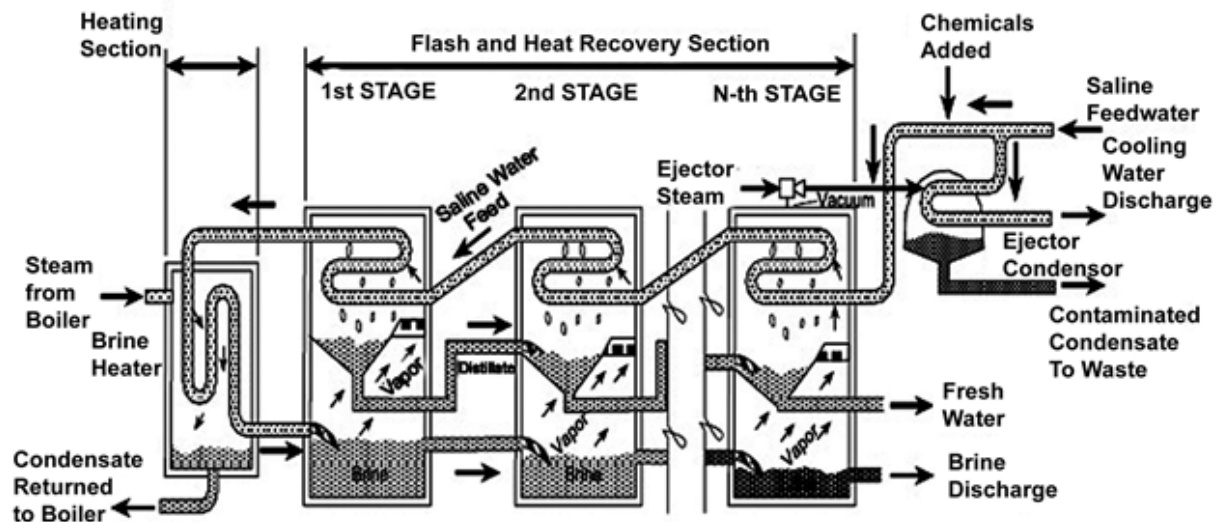


Figure 3.2 Mechanism of Multi-stage Flash Desalination[10]

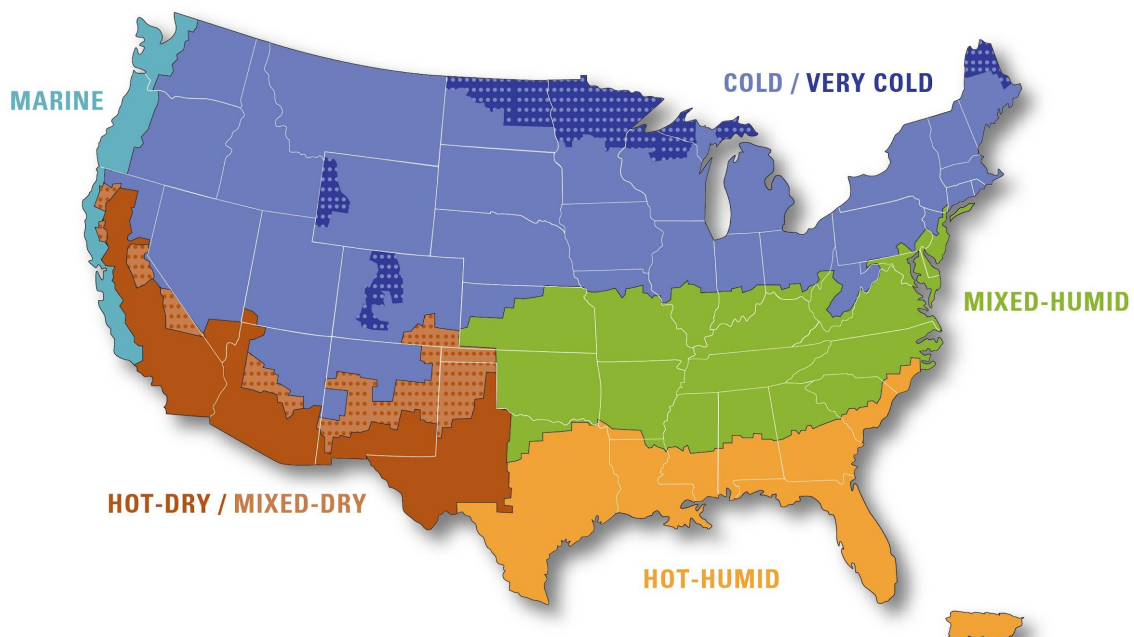


Figure 3.4 Climate Zones of the United States

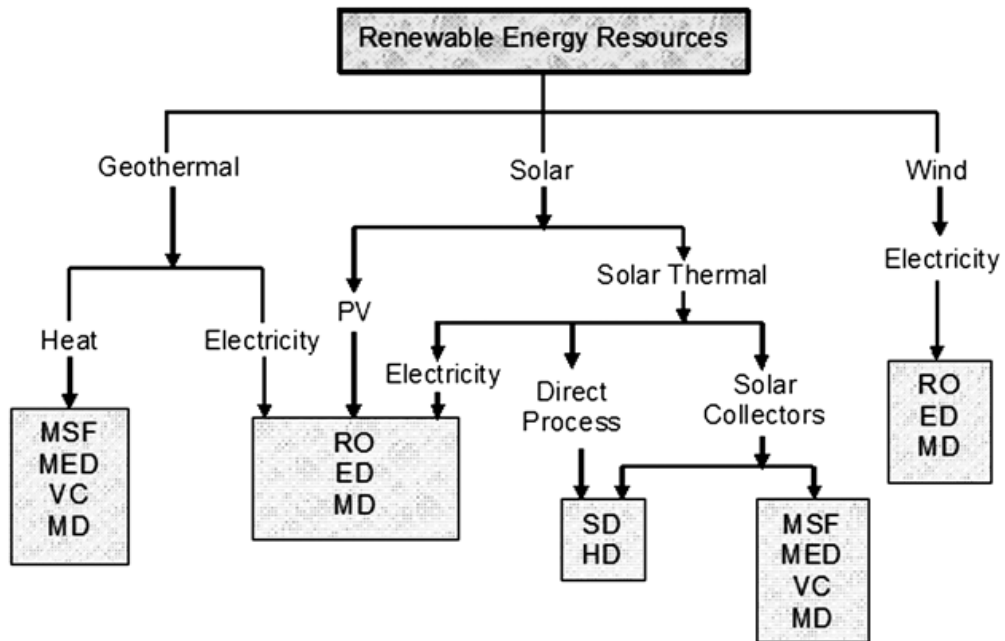


Figure 3.5.1 Types of Renewable Desalination [15]

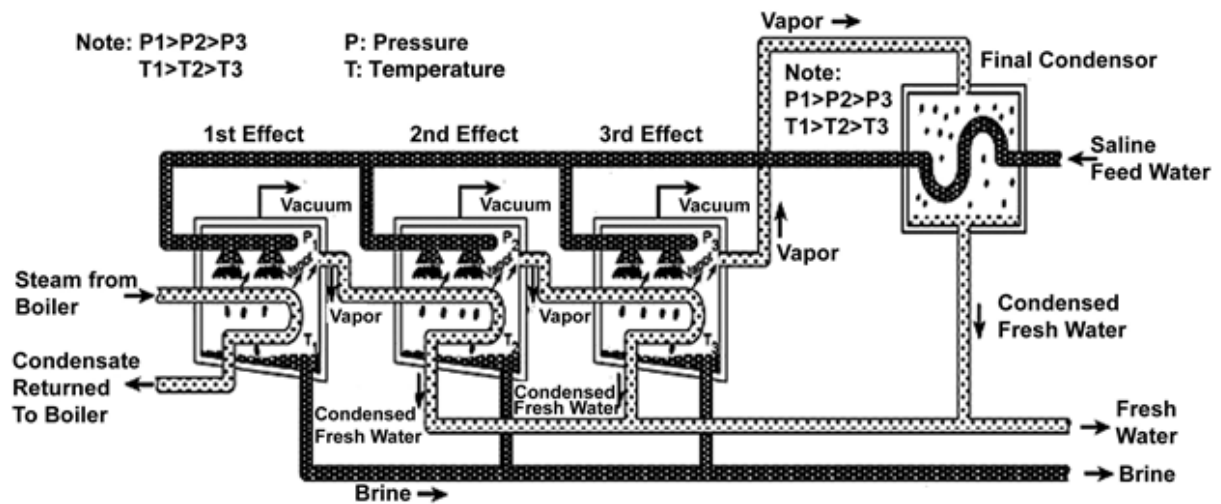


Figure 3.5.2 Mechanism of Multiple-effect Distillation [15]

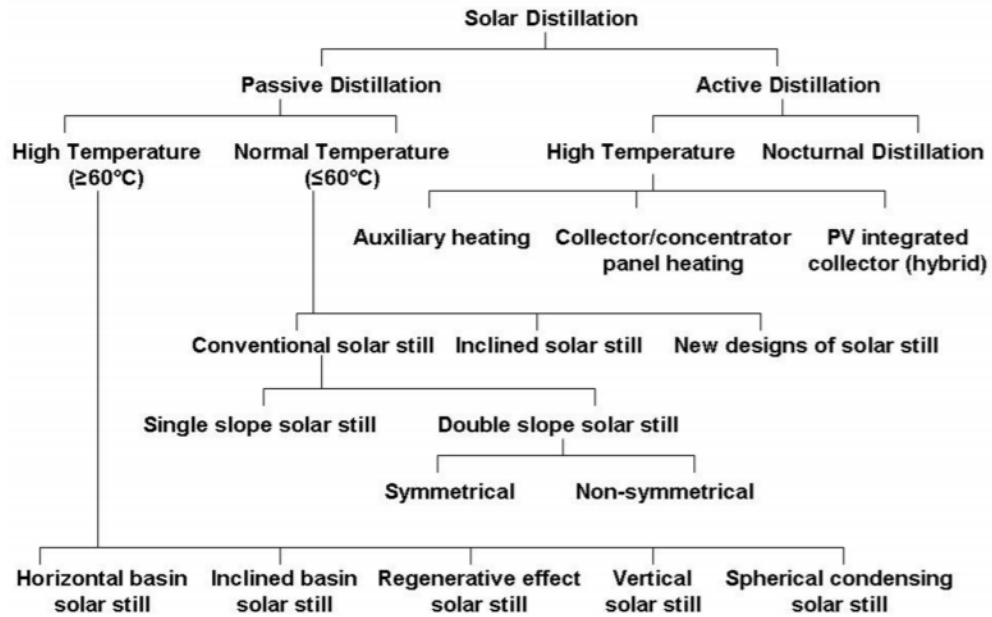


Figure 3.5.3 Type of Solar Distillation [20]

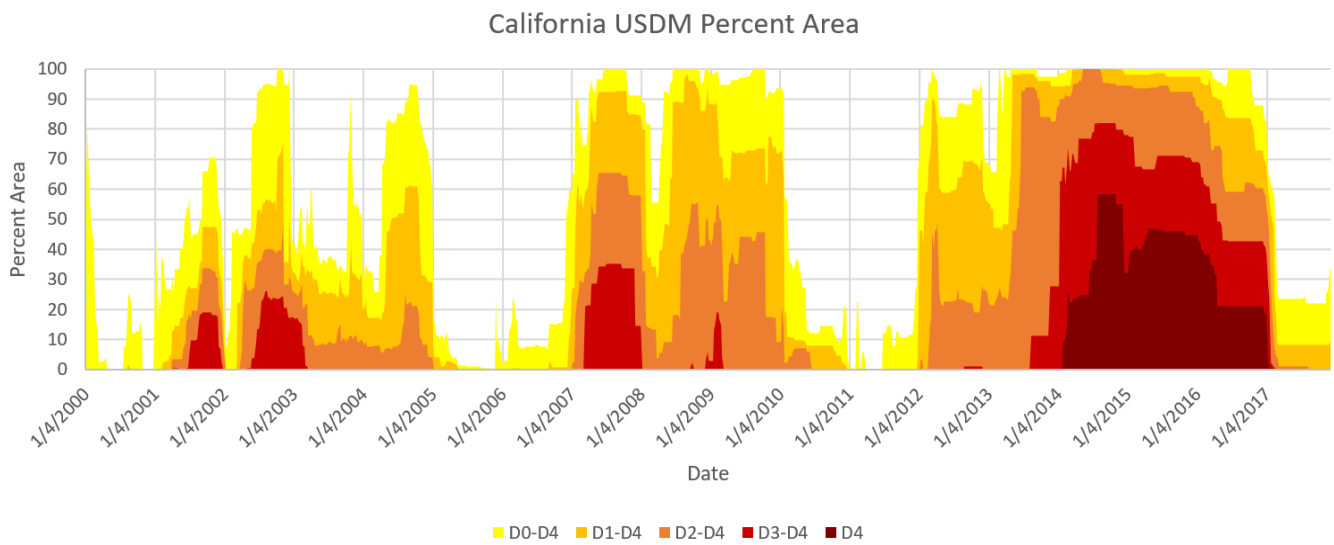


Figure 5.1.1 Drought History from 2000-2017 in California Cumulative Drought Intensities [24]

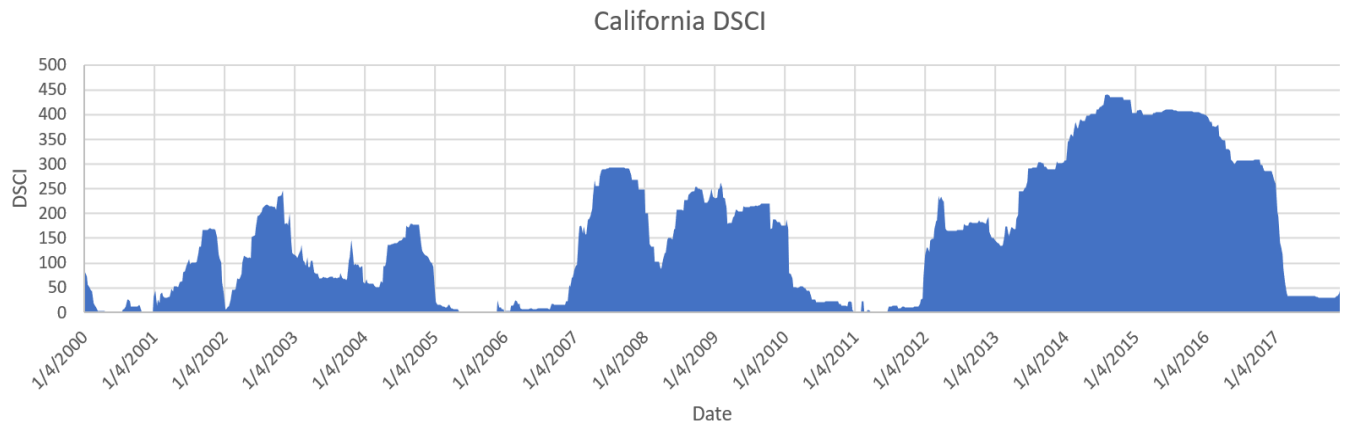


Figure 5.1.2 *Drought History from 2000-2017 in California DSCI [24]*

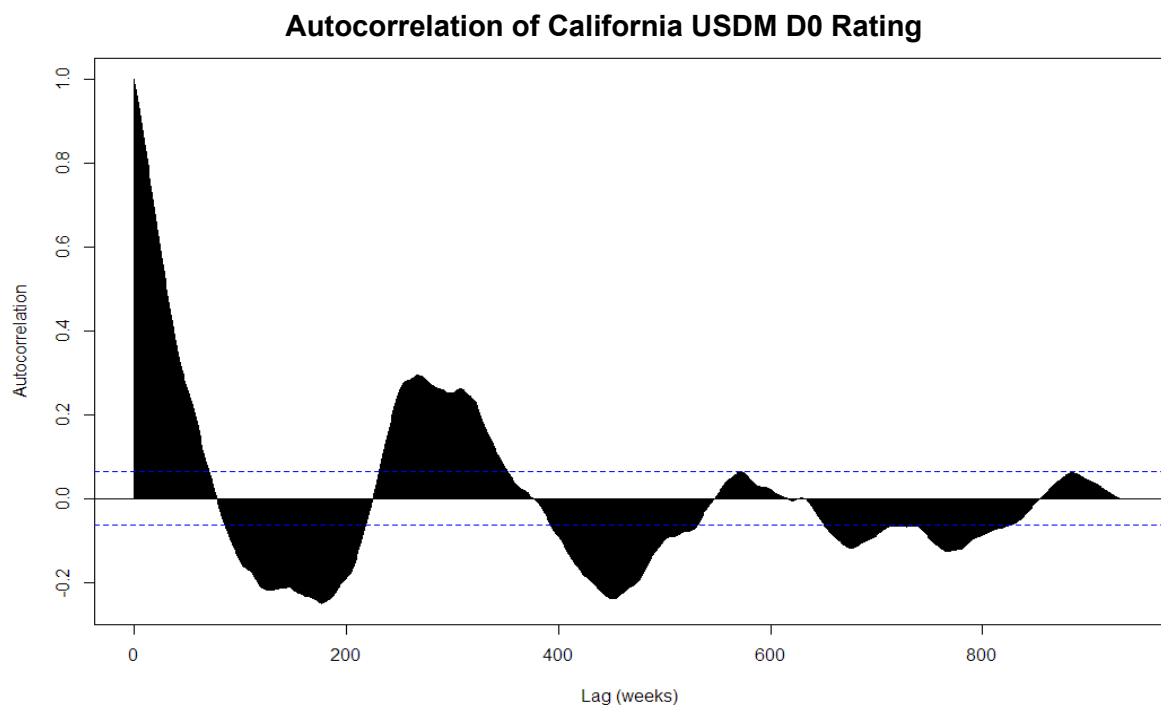


Figure 5.1.3 *Autocorrelation Plot of California using USDMD0 Rating [24]*

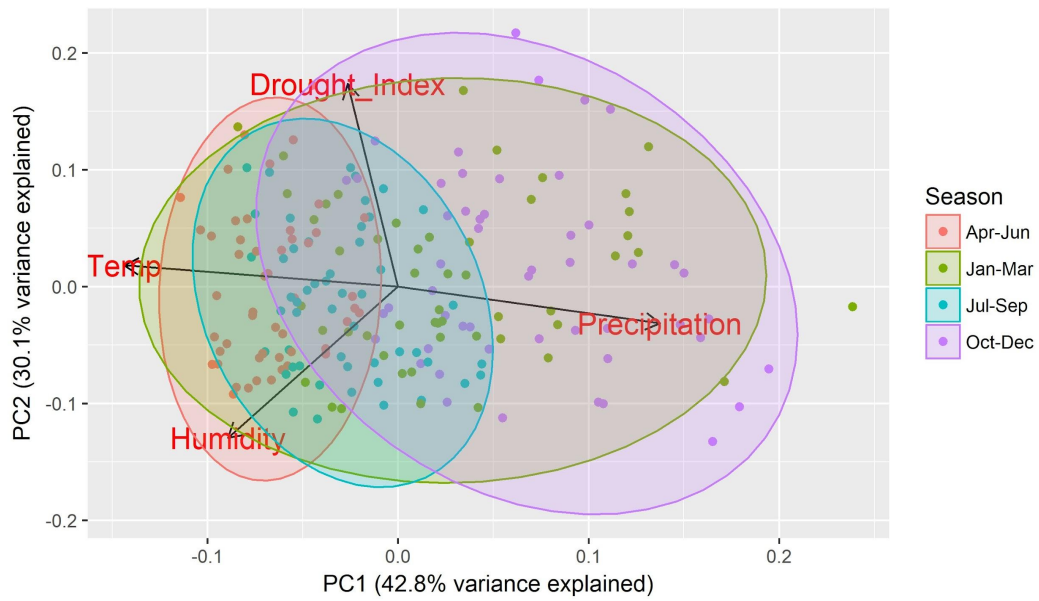


Figure 5.2 Data Plot of Principal Component Analysis

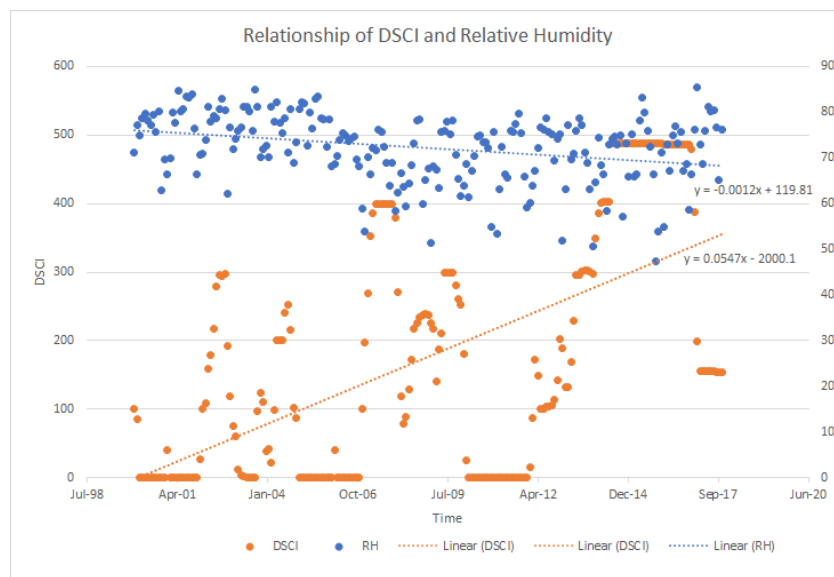


Figure 5.3 Time series of DSCI and Relative Humidity[26]

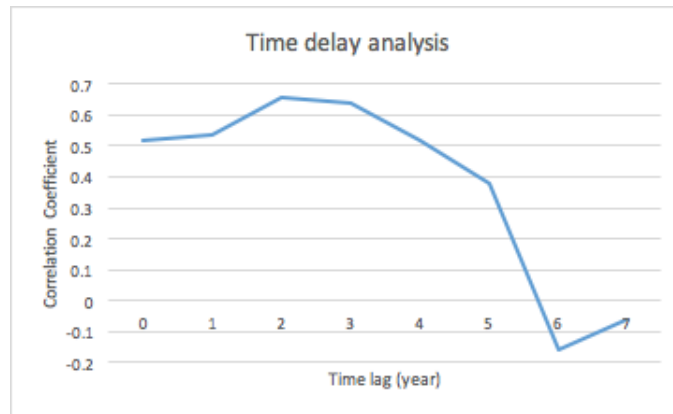


Figure 5.4.1 *Time delay analysis between DSCI and Real Agricultural Income* [27][28]

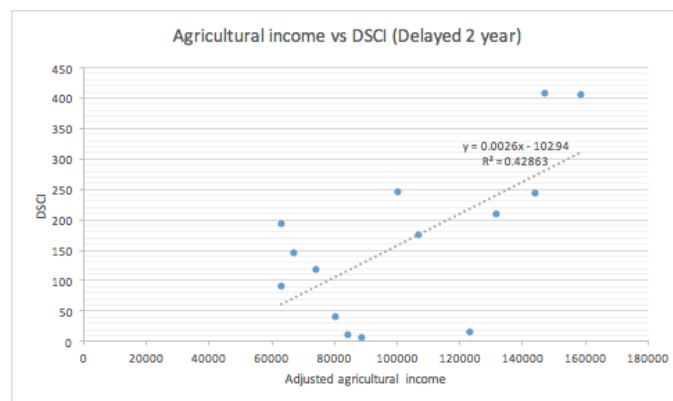


Figure 5.4.2 *Scatter plot between DSCI and Real Agricultural Income with 2 years time lag* [27][28]

9. References

- [1] "Water scarcity | International Decade for Action 'Water for Life' 2005-2015", Un.org, 2017. [Online]. Available: <https://www.un.org/waterforlifedecade/scarcity.shtml>. [Accessed: 05- Nov- 2017].
- [2] J. Mount and E. Hanak, "Water Use in California," Water Use of California - Public Policy Institute of California, Jul-2016. [Online]. Available: <http://www.ppic.org/publication/water-use-in-california/>. [Accessed: 04-Nov-2017].
- [3] "California Department of Food and Agriculture," CDFA. [Online]. Available: <https://www.cdfa.ca.gov/CDFA-History.html>. [Accessed: 04-Nov-2017].
- [4] United States Drought Monitor. (2017). Drought Classification. [online] Available at: <http://droughtmonitor.unl.edu/AboutUSDM/DroughtClassification.aspx> [Accessed 24 Nov. 2017].
- [5] "2010 California Water Use Data | USGS," United States Geological Survey. [Online]. Available: https://ca.water.usgs.gov/water_use/2010-california-water-use.html.
- [6] "Groundwater Information Center", Water.ca.gov, 2017. [Online]. Available:

<http://www.water.ca.gov/groundwater/gwinfo/>. [Accessed: 05- Nov- 2017].

[7] E.G and B.JR, "Spring 2017 Groundwater Level Data Summary – Final Draft," vol. 1, no. 916, 2017.

[8] "California's Wild Climate Will Only Get More Volatile As Temperatures Rise", HuffPost UK, 2017. [Online]. Available:
https://www.huffingtonpost.com/entry/california-climate-temperature_us_58a49f38e4b03df370dca5cf

[9] "We Are All Californians Now", National Review, 2017. [Online]. Available:
<http://www.nationalreview.com/article/420652/we-are-all-californians-now-victor-davis-hanson>.
[Accessed: 05- Nov- 2017].

[10] "Drivers of Change", Ppic.org, 2017. [Online]. Available:
http://www.ppic.org/content/pubs/report/R_211EHChapter3R.pdf. [Accessed: 05- Nov- 2017].

[11] Meisen, P. and Phares, N. (2011). Impacts of Climate Change on California's Water Supply. Global Energy Network Institute. [online] Available at:
<http://www.geni.org/globalenergy/research/impact-of-climate-change-on-californias-water-supply/Impacts%20of%20Climate%20Change%20on%20California%92s%20Water%20Supply.pdf> [Accessed 14 Dec. 2017].

[12] Wri.org. (2017). Drought Is Only One Explanation for California's Water Crisis | World Resources Institute. [online] Available at:
<http://www.wri.org/blog/2014/03/drought-only-one-explanation-california%E2%80%99s-water-crisis>
[Accessed 13 Dec. 2017].

[13] Public Policy Institute of California. (2016). How Is California Spending the Water Bond? - Public Policy Institute of California. [online] Available at:
<http://www.ppic.org/blog/how-is-california-spending-the-water-bond/> [Accessed 13 Dec. 2017].

[14] Mercurynews.com. (2017). New dams for California? A dozen projects seek \$2.7 billion. [online] Available at:
<http://www.mercurynews.com/2017/08/15/new-dams-coming-to-california-a-dozen-projects-seek-2-7-billion-in-state-funding/> [Accessed 13 Dec. 2017].

[15] M. Shatat and S. Riffat, "Water desalination technologies utilizing conventional and renewable energy sources", OUP Academic, 2017. [Online]. Available:
<https://academic.oup.com/ijlct/article/9/1/1/663897>. [Accessed: 12- Dec- 2017].

[16] "Sidem | Veolia Water Technologies | MSF - Multi-stage flash distillation process", Sidem-desalination.com, 2017. [Online]. Available:
<http://www.sidem-desalination.com/Process/Thermal-desalination-MED/MSF/>. [Accessed: 12- Dec- 2017].

- [17] "Mineral and Energy Resources of the Sea", Soest.hawaii.edu, 2017. [Online]. Available: http://www.soest.hawaii.edu/oceanography/courses/OCN330/Fall2011/11_Desalination.pdf. [Accessed: 12- Dec- 2017].
- [18] "Fog harvesting," 1.3 Fog harvesting. [Online]. Available: <https://www.oas.org/dsd/publications/unit/oea59e/ch12.htm>. [Accessed: 12-Dec-2017].
- [19] "HydroRevolution - WaterFX", WaterFX, 2017. [Online]. Available: <http://waterfx.co/hydrorevolution/>. [Accessed: 12- Dec- 2017].
- [20] "Solar Stills for Desalination of Water in Rural Households ", Sciencetarget.com, 2017. [Online]. Available: <https://www.sciencetarget.com/Journal/index.php/IJES/article/download/326/79>. [Accessed: 12- Dec- 2017].
- [21] "Agricultural Land Loss & Conservation", Cdfa.ca.gov, 2017. [Online]. Available: https://www.cdfa.ca.gov/agvision/docs/Agricultural_Loss_and_Conservation.pdf. [Accessed: 12- Dec- 2017].
- [22] "Los Angeles, California Climate", Bestplaces.net, 2017. [Online]. Available: http://www.bestplaces.net/climate/city/california/los_angeles. [Accessed: 12- Dec- 2017].
- [23] "Aqua4™ - WaterFX", WaterFX, 2017. [Online]. Available: <http://waterfx.co/aqua4/>. [Accessed: 12-Dec- 2017].
- [24] "Comprehensive Statistics", droughtmonitor.unl.edu. (2017). Comprehensive Statistics. [online] Available at: <http://droughtmonitor.unl.edu/Data/DataDownload/ComprehensiveStatistics.aspx> [Accessed 13 Dec. 2017].
- [25] N. (NCDC), "Local Climatological Data Publication | IPS | National Climatic Data Center (NCDC)", Ncdc.noaa.gov, 2017. [Online]. Available: <https://www.ncdc.noaa.gov/IPS/lcd/lcd.html>. [Accessed: 27- Nov- 2017].
- [26] Mesonet.agron.iastate.edu. (2017). IEM :: Download ASOS/AWOS/METAR Data. [online] Available at: https://mesonet.agron.iastate.edu/request/download.phtml?network=CA_ASOS# [Accessed 13 Dec. 2017].
- [27] "CDFA > STATISTICS", Cdfa.ca.gov, 2017. [Online]. Available: <https://www.cdfa.ca.gov/statistics/>. [Accessed: 13- Dec- 2017].

[28] "GDP deflator (base year varies by country) | Data", Data.worldbank.org, 2017. [Online]. Available: https://data.worldbank.org/indicator/NY.GDP.DEFL.ZS?locations=US&name_desc=false. [Accessed: 13- Dec- 2017].

[29] Misbrener, K. (2017). What is the life expectancy of a solar array?. [online] Solar Power World. Available at: <https://www.solarpowerworldonline.com/2017/01/life-expectancy-solar-array/> [Accessed 14 Dec. 2017].

[30] Kurup, P. and Turchi, C. (2015). Parabolic Trough Collector Cost Update for the System Advisor Model (SAM). National Renewable Energy Laboratory. [online] Available at: <https://www.nrel.gov/docs/fy16osti/65228.pdf> [Accessed 15 Dec. 2017].